Remote Identification of Seafloor Properties in Denied Areas

Larry Mayer, Luciano Fonseca, and Thomas Weber
Center for Coastal and Ocean Mapping
University of New Hampshire
Durham, NH 03824
Phone: (603) 862-2615 fax: (603) 862-0839 email: lmayer@cisunix.unh.edu

Co-P.I.: Art Trembanis,
Coastal Sediments Hydrodynamics and Engineering Lab, Department of Geological Sciences
University of Delaware
109 Penny Hall
Newark, DE 19711
Phone: (302) 831-2498 email: art@udel.edu

Award Number N00014-07-1-0666
http://www.ccom.unh.edu

LONG-TERM GOAL

The long-term goal of this project is to develop techniques to collect and use remotely sensed acoustic data to make robust predictions of seafloor physical, acoustic and geotechnical properties in denied areas at spatial and temporal scales appropriate for tactical applications. The work described is a collaboration of research groups at the University of New Hampshire (CCOM) and the University of Delaware (CSHEL). The project aims to take advantage of the recent results of theoretical and empirical studies in concert with new developments in sonar and Autonomous Underwater Vehicles (AUVs), to address the fundamental goal of remote characterization of seafloor properties in denied areas.

OBJECTIVES

1- Continue the development of a physics-based model (ARA) for the prediction of seafloor properties from remotely collected acoustic backscatter data

2- Test, validate, and update the model through the collection of carefully controlled ground-truth samples. In doing this we will also be adding to a growing database of physical and acoustic property measurements and inter-relationships.

3- Evaluate the feasibility of applying remote characterization algorithms to data collected with a small, low-powered phase measuring bathymetry sonar (PMBS) deployed from an autonomous underwater vehicle.

APPROACH

Our initial approach involves four inter-related tasks: model development; ground-truth studies; swath bathymetry evaluation, and; AUV integration. Some of these tasks have been pursued independently and the results of these independent efforts are now being brought together. This past year our efforts have focused on model development and the use of a new swath mapping system and AUV.

Remote seafloor characterization using the ARA model:

With the development of multibeam echo-sounders the ability to look at the angular dependence of the acoustic response of the seafloor has opened up many new possibilities with respect to seafloor characterization. The angular response of the echo holds important information about seafloor roughness and volume reverberation, as well as acoustic impedance. Over the past few years, researchers at the University of New Hampshire have been developing a sophisticated sonar backscatter mosaicking tool (Geocoder – Fonseca and Calder, 2005) which includes a physics-based model known as ARA (Angular Response Analysis) that uses the angular dependence of backscatter for the remote prediction of seafloor properties. The ARA technique corrects multibeam sonar backscatter for radiometric and geometric factors, parameterizes the corrected angular response curve, and then applies a constrained (based on known physical property relationships) inversion (either a modified Jackson/Williams model or a Biot model) to solve for seafloor type including acoustic impedance, roughness and grain size (Fonseca et al., 2005; Fonseca and Mayer, 2007). The model has been packaged in an interactive software tool that allows the rapid determination of the seafloor properties (Fig 1.).

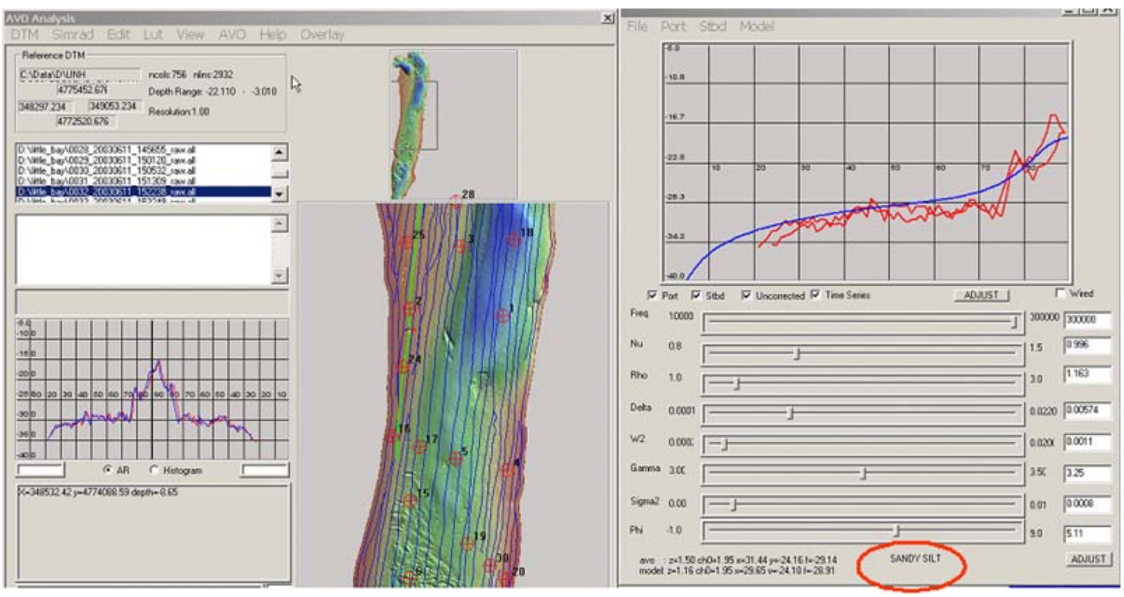

Figure 1. ARA tool with angular response curve and inverted solution for sediment type

ARA-Analysis of Acoustic Themes, Over-segmentation and Thematic Coagulation:

ARA-analysis is normally applied to seafloor patches that are typically half a full-swath width wide in the across-track direction, and 30 pings in the along-track direction (Fonseca and Mayer 2007). However, the low spatial resolution of these seafloor patches is an issue in areas of high spatial variability. To address this issue we have developed an approach that uses the high spatial resolution of the backscatter mosaic to visually define areas of the seafloor with similar angular responses - "acoustic themes" - and then calculate an average angular response per acoustic theme, rather than across the sonar swath. This approach has already provided robust estimates of seafloor properties in areas of high spatial variability (Luis Ruis, 2007; Fonseca et al., 2008).

While the initial "acoustic theme" generation was done by hand, we are now working on methods for automatically segmenting the image simultaneously in both the textural space and in the angular response space. This new approach is based on the use of spatial segments of intermediate size (between the pixel and the full swath), which we assume to be homogenous. The assumption of segment homogeneity relies on the information extracted from the backscatter mosaic. Backscatter mosaics depict many boundaries, some related to actual changes in seafloor facies and others that are artifacts of the acquisition or the mosaicking process. From the mosaic alone, the artifacts cannot be distinguished from the real boundaries. To automatically segment the mosaic we apply an over-segmentation technique which generates a comprehensive set of the smallest possible segments which preserve spatial similarity, honoring all the boundaries in the mosaic (Fonseca and Rzhanov 2008). These small segments have a more complete angular coverage than pixels described above, but still do not have the full angular response required for accurate seafloor characterization. Hence, segments need to be coalesced with similar and/or adjacent segments in order to generate areas on the seafloor with sufficient angular coverage to allow for application of the ARA method and seafloor characterization.

Interferometric Swath Bathymetry Sonar and AUV:

In order to provide a seafloor characterization system in denied areas, we must strive to deliver our remote seafloor characterization capability on an autonomous vehicle that can operate covertly. Our efforts this year have thus also focused on the evaluation of a newly introduced, small-footprint, low-power phase measuring bathymetry sonar system (GeoAcoustics GeoSwath-Plus) and the integration of this system into an autonomous underwater vehicle (The University of Deleware's DORA vehicle – a Gavia class AUV). Our approach was to test the capability of the GeoSwath PMBS to determine if it is feasible to apply the ARA technique to the data collected from it while at the same time evaluating the capabilities of the DORA AUV so as to evaluate its appropriateness as a platform for the remote characterization objectives of this project.

WORK COMPLETED

Geocoder/ARA Modeling:

The Geocoder/ARA backscatter analysis package continues to evolve. Support has been added for a number of new sonar systems including Reson 7K series, Seabeam 2100 series, Simrad EA600 sidescan sonars, and the new Benthos C3D system and a graphical tool has been added to edit and interpret the selection of response curve parameter in the slope/intercept plane. Additionally, the ability to incorporate backscatter from multiple frequencies over the same piece of seafloor has been added to the ARA. As seafloor mapping sonars become broader band, the ability to handle multiple frequencies may hold great potential for additional seafloor characterization information. Most importantly, a fundamental constraint of the ARA approach (the need to average over a swath-width in both the across-track and the along-track direction – which limits the spatial resolution) has been addressed through the development of "thematic analysis". The thematic analysis examines the angular response of small areas on the seafloor and then segments the entire region into areas of common angular response. This past year we have successfully demonstrated automated approaches to thematic segmentation (Fonseca and Rzhanov, 2008).

GeoSwath PMBS:

The GeoSwath-Plus is a wide swath bathymetric sonar designed as a payload sonar on survey class remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs). The GeoSwath ROV/AUV unit is based on the same sonar technology as that used in the boat-mounted GeoSwath system. The GeoSwath PMBS sonar has been designed specifically for AUV deployment, with design modifications to make the unit more modular, smaller, and to reduce power consumption. The GeoSwath-Plus, as incorporated in the UD AUV (DORA), operates at 500 kHz and can obtain bathymetric soundings along with co-registered digital side-scan sonar to depths of 200 m with swath coverage of up to 12 times water depth. Additional inputs to the system include sound velocity (micro-SVS sensor), vehicle position and attitude (a DVL-aided INS/GPS system).

DORA (Gavia Class) AUV Evaluations:

A close collaboration has been established between the UNH and UDel teams including many exchanges of equipment and personnel over the last 3+ years. The GeoSwath PMBS has previously been fully integrated into the Gavia AUV and was tested and acquired by UDel in 2008 (Fig. 2) and, most importantly to the project objectives, the CCOM-UNH Geocoder software has been developed to accept data from the GeoSwath unit for ARA processing. Our emphasis has been on acquiring actual field survey data from diverse sedimentary settings to allow a broad assessment of both the GeoSwath PMBS and of the Geocoder ARA algorithm development. To that end, field surveys with the GeoSwath equipped Gavia AUV have been conducted in 2008 in settings including shallow and deep carbonate platforms (Bonaire, Netherlands Antilles- Trembanis, 2008 -- Fig 2); energetic estuaries such as Great Bay, New Hampshire, and Delaware Bay.

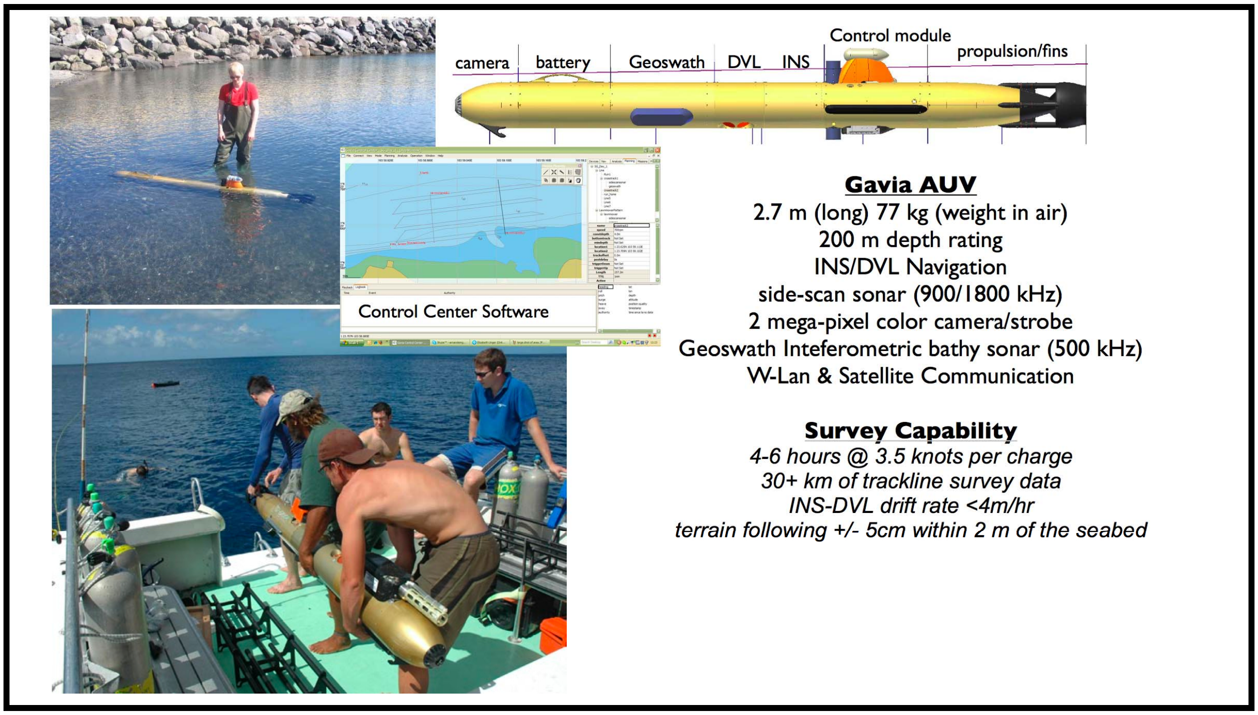

Figure 2. DORA AUV with GeoSwath Phase Measuring Bathy Sonar module undergoing trials

Data Formats and Preliminary Backscatter Processing

The GeoSwath is a phase comparison swath sonar whose data formats are very different from standard multibeam sonars. Thus, in the past year we have had to develop special software to convert the native GeoSwath RDF files into standard Generic Sensor Format (GSF), so that Geocoder and the ARA analysis tools could be run on the GeoSwath data. We also needed to modify the analytical approach. Initially, the individual sidescan samples produced by the GeoSwath system, with the accompanying angle of arrival solutions, were treated as “multibeam” beams, so that an approach similar to that used to analyze standard multibeam sonar backscatter could be applied. However, the number of samples produced by the Gavia system is very high and the angle solutions are very noisy, so that not all the beams could be used for the geometric correction. In order to overcome this limitation, the approach had to be modified to follow the paradigm of a sidescan sonar, treating the set of samples as a time series, and not beams, with a subset of beams used as tie points for the geometric corrections.

The result of this processing is the adjusted mosaic and the corrected backscatter angular response of the system (Figure 3). This angular response will be can then me compared to a mathematical model of seafloor acoustic response, and the ARA inversion of the model used to predict seafloor properties. There are no models currently available in the literature that are have proven to reliably simulate the backscatter response at very high frequencies (in our case 500 kHz). We are thus expanding our research effort to include the modeling of acoustic response at these very high frequencies.

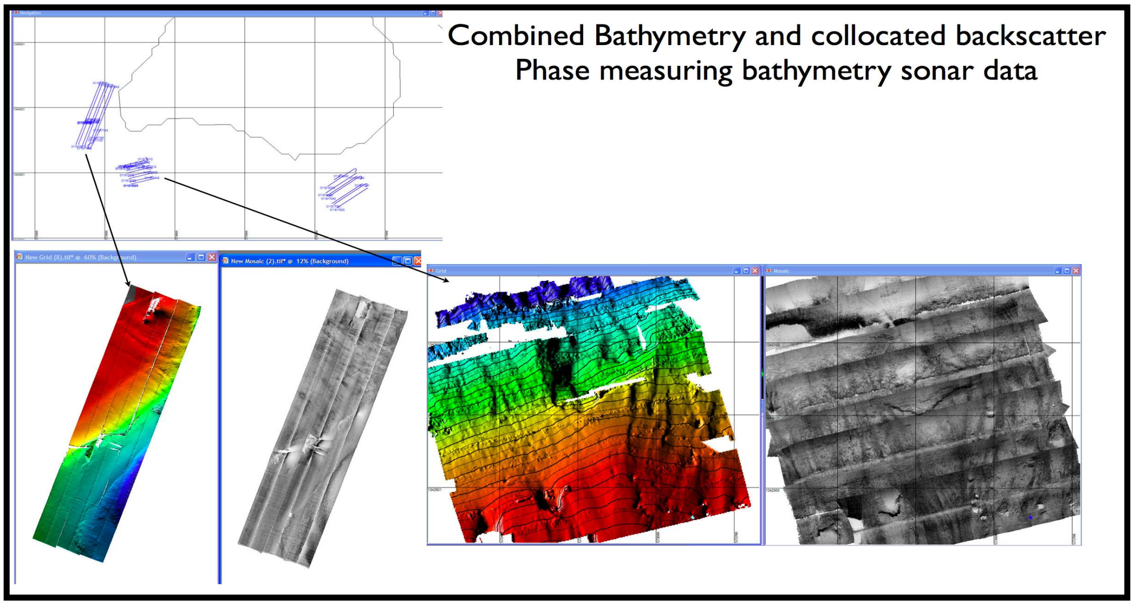

Figure 3. Results of AUV field survey data collected off the island of Bonaire, Netherlands Antilles and available for seafloor classification algorithm development.

RESULTS

AUV Results:

With the acquisition of the Gavia AUV and integration of the GeoSwath module we moved into the field data collection phase of the project. Field data collection was done on an *ad hoc* basis whenever personnel and/or ship time became available for operations. In total over 19 days of field operations and more than 30 individual missions (commanded survey runs) were conducted in the following diverse coastal locations: Bonaire, Netherlands Antilles (Figure 3); Delaware Bay entrance (Figure 4); and Great Bay, NH. The field campaigns included tests of the vehicle stability for precision control during seafloor mapping. Results indicate that the vehicle is capable of very stable flight within 5 cm of commanded terrain altitude at speeds of 1.5 - 2 m/s in settings where tidal currents were flowing at speeds of 0.5-0.7 m/s. In addition to these stability tests, survey data was used to evaluate the positioning precision by comparing repeated measurements of distinct hard targets in the sonar data imaged over an hour apart in time (Figure 5).

In the course of our field campaigns we amassed more than 10 gB of raw GeoSwath data files that were used in the evaluation and software development effort and remain archived and available for PMBS system evaluation. However, given the *ad hoc* nature of the field campaigns a full a sufficient suite of ground truthing data was not concomitantly collected. It is worth noting that for the case of GeoSwath data collected in the clear waters of Bonaire, optical images of the seabed exist when lighting and range permitted and these images provide a useful reference for ground truthing of the acoustic imagery.

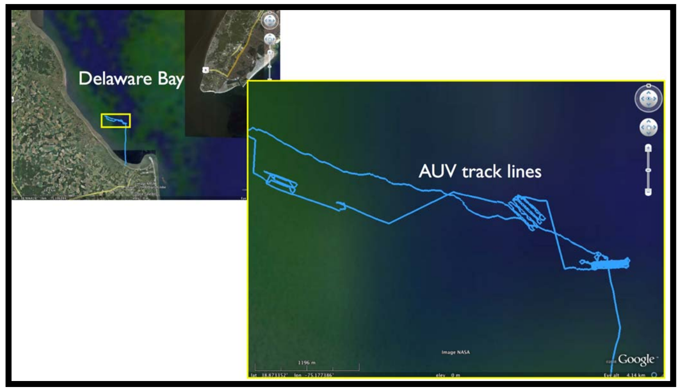

Figure 4. AUV field survey tracklines from July 2008 inside the mouth of Delaware Bay.

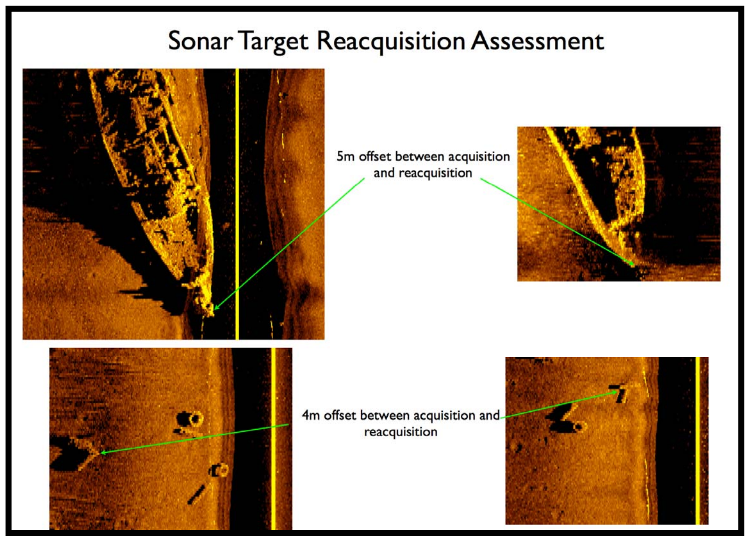

***Figure 5.** Target re-acquisition assessment from repeated measurement of hard targets in side-scan sonar data stamped with INS-DVL navigation information.*

Phase Measuring Bathy Sonar Evaluations:

Initial tests in Bonaire verified the functionality of the GeoSwath both for the collection of bathymetry and quantitative backscatter data (Fig 6). During subsequent field tests in New Hampshire, a software configuration setting problem disabled the transmit pulse of the GeoSwath and thus no additional backscatter data were collected. The New Hampshire campaign did, however, allow for the testing of a number of Gavia configuration procedures and provided for useful development exchanges between the AUV manufacturer and the PMBS manufacturer. Software fixes were implemented during the subsequent Delaware field campaign and a large body of useful GeoSwath data was collected and are continuing to be analyzed for ARA algorithm development.

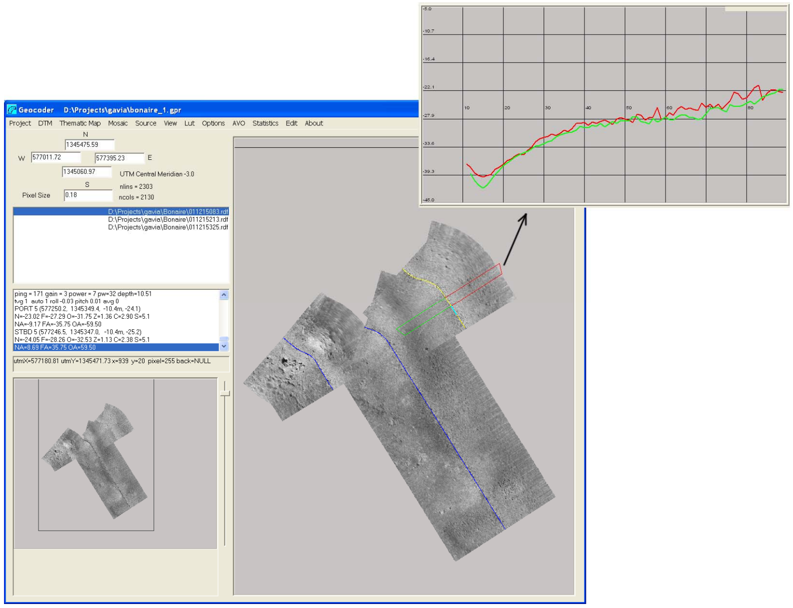

Figure 6 – Gavia GeoSwath mosaic from the Bonaire area with corrected angular response

IMPACT/APPLICATIONS

Results from validation of ARA approach imply that within limits it may offer a robust prediction of seafloor properties. If this continues to be proven true, the development of an AUV-deployed system will offer an approach for estimating seafloor physical, acoustic and geotechnical properties in denied areas at spatial and temporal scales appropriate for tactical applications.

TRANSITIONS

Geocoder/ARA have been transferred and are now being implemented by numerous industrial partners including CARIS, IVS, Fugro, Kongsberg/Simrad, Reson, Triton, HYPACK, and Chesapeake Technologies as well as several NOAA labs. It is also in use by numerous university labs.

RELATED PROJECTS

Fluid-Mud Interaction MURI
NOAA-OE Bonaire 2008 Remote habitat mapping in a tropical shelf setting
NOAA-SG Baymouth Circulation- Badiey, Wong, and Trembanis: 3 cruises aboard the R/V Sharp afforded at sea trials and testing of the AUV/multibeam system. The SG project benefited from the situational visualization system that was made available during the cruises
NSF-DE-EPSCoR- Pepper Creek: Trembanis, Targett, diToro: 4 field surveys at Pepper Creek DE afforded on the water testing of the AUV/multibeam system. The EPSCoR project benefited from the situational visualization system that was made available during the field work

REFERENCES (not listed in Publications)**:**

Fonseca, L. and Calder B. (2005), "Geocoder: and Efficient Backscatter Map Constructor ", Proceedings of the U.S. Hydrographic 2005, San Diego, CA.

Fonseca L., Mayer L.A., Kraft B., 2005, Seafloor characterization through the application of AVO analysis to multibeam sonar data. In: Pace NG, Blondel P (Eds) Boundary Influences In *High Frequency, Shallow Water Acoustics. Institute of Acoustics*, Bath University Press, pp 241-250.

Hamilton, E. (1974), "Prediction of deep-sea sediment properties: state-of-the-art", In, *Deep-Sea Sediments, Physical and Mechanical Properties,* Plenum Press, pp. 1-43

Soares Rosa, Luis, 2007, Seafloor Characterization at the Historic Area Remediation Site using Angular Response Analysis, M Sc. Thesis, University of New Hampshire, 102 pp.

PUBLICATIONS

Fonseca, L., Brown, C., Calder, B., Mayer, L. and Rzhanov, Y. (2008), "Angular Range Analysis of the Seafloor Themes from Stanton Banks Ireland: A Link between Visual Interpretation and Acoustic Signatures", Journal of Applied Acoustic, Special Issue, Accepted for Publication (Refereed publication).

Fonseca, L. and Rzhanov, Y. (2008), "Automatic Construction of Acoustic Themes from Multibeam Backscatter Data", Shallow Survey 2008, Portsmouth NH.

Fonseca, L. and Calder, B. (2007), "Clustering Acoustic Backscatter in the Angular Response Space", Proceedings Hydro 2007, Norfolk, VA

Fonseca, L., Calder, B.R., and Wetzler, M., 2006, Experiments for Multibeam Backscatter Adjustments on the NOAA Ship Fairweather, Oceans 2006: Boston, MA.

Fonseca, L., and Mayer, L.A., 2007, Remote estimation of surficial seafloor properties through the application Angular Range Analysis to multibeam sonar data: Marine Geophysical Researches, p. 119-126. (Refereed Publication)

Fonseca, L., Mayer, L.A., and Brown, G., 2007, Angular Range Analysis of the acoustic Backscatter from Stanton Banks, Ireland, Femme 2007 EM Multibeam Experience: Amsterdam, Netherlands
.

Forrest, A.L., B.E. Laval, D. Lim, A. Trembanis, E. Magnusson, R. Yeo and C.P. McKay, in review. Autonomous Underwater Vehicles: Robotic analogues for space exploration. Journal of Planetary and Space Science.

Griffiths, G. and Trembanis, A., 2007. Eliciting expert judgement for the probability of AUV loss in contrasting operational environments. Published proceedings of the UUST, New Hampshire, August 2007.

Griffiths, G. and Trembanis, A.C., 2007. Towards a risk management process for Autonomous Underwater Vehicles. Pp. 103-118 in: Griffiths, G. and Collins, K., Proceedings of a

Masterclass on AUV Technology for Polar Science. Society for Underwater Technology, London.

PRESENTATIONS

Fonseca, L. “Backscatter Mosaics and Acoustic Seafloor Characterization”, Invited Talk, 2008 Hypack Training Seminar, Savanna, Georgia 7 January 2008

Fonseca, L, “Geocoder: Acoustic themes and ARA seafloor Characterization”, NOAA Ship FAIRWEATHER, August 24th, 2008.

Fonseca, L, “Geocoder: Acoustic themes and ARA seafloor Characterization”, NOAA Ship RANIER, August 25th, 2008.

Mayer, L.A., “Seafloor Characterization”, Invited lecture Gescience Australia, Cairns Australia, 30 April 2008

Trembanis, A. “Using Autonomous Underwater Vehicles in Coastal Science”. Invited seminar Indiana University of Pennsylvania. Dept of Geosciences. September 15th, 2008

Trembanis, A., “Mapping Bonaire’s Reef Using High Tech Robots and Mixed Gas Diving”. Dept. of Geological Sciences Spring Seminar

Patterson, M., and A.C. Trembanis, “Mapping Bonaire's Reefs Using High Tech Robots and Mixed Gas Diving”. CIEE/STINAPA sponsored public lecture Bonaire, Netherlands Antilles. Jan. 28th, 2008.